

# Validation and Enhancement of AMSR-E Cloud and Precipitation Products

## Progress and Planned Research

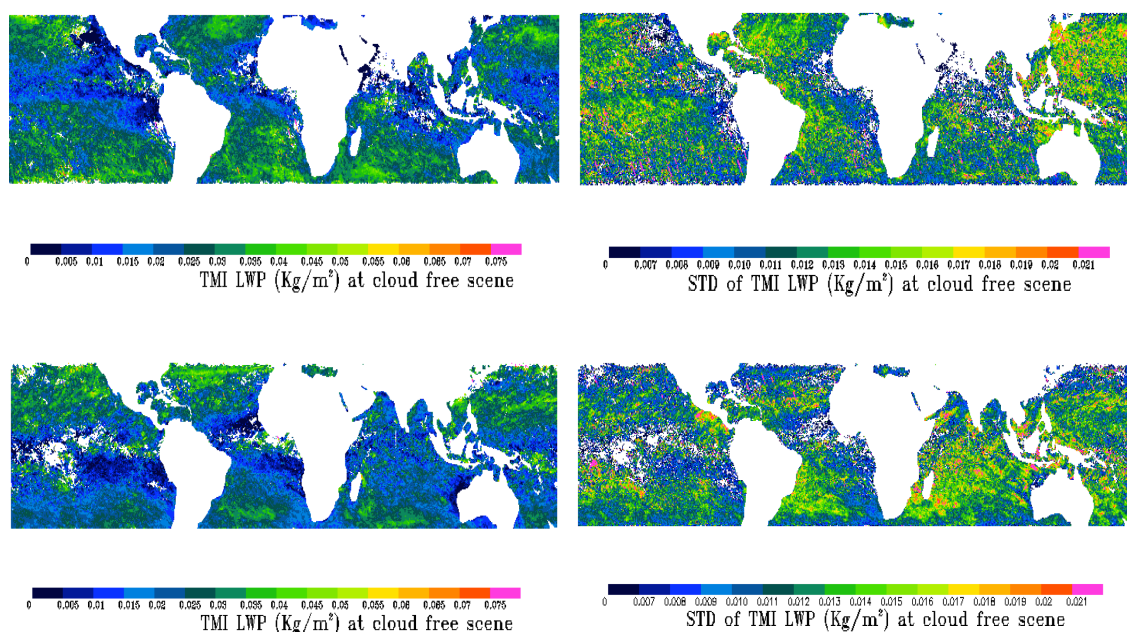
Our research project on AMSR-E cloud and precipitation products has been progressing on parallel tracks. As originally proposed, the project had four goals: (1) Coordinate validation activities between CloudSat and AMSR, (2) Provide ground truth of cloud liquid water, (3) Provide correlative evaluation of cloud liquid water, and (4) Provide physical precipitation validation and correlative analyses. Our efforts to date have emphasized correlative studies of the retrieval of cloud liquid water path and preparation for and participation in the Wakasa Bay validation campaign. Because much of the retrieval work is dependent on data from the Wakasa Bay experiment, our research results are necessarily weighted towards the latter half of our project term.

### 1. Evaluating Cloud Liquid Water Path Estimates (T. S. L'Ecuyer in collaboration with T. Greenwald and S. Christopher)

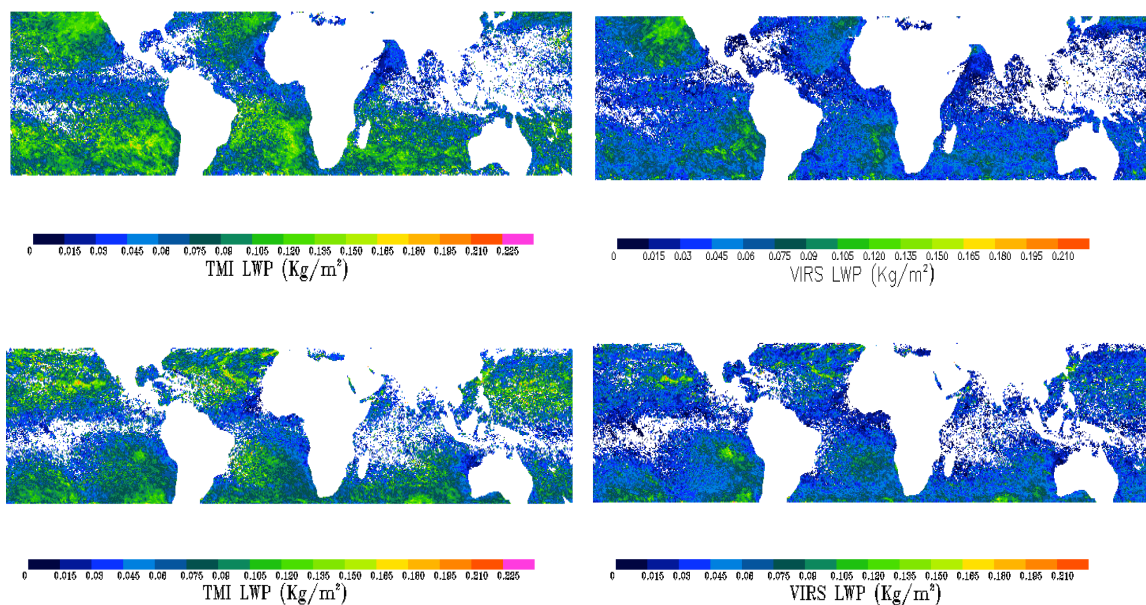
Global weather patterns are driven by the exchange of energy between the sun, atmosphere, surface, and space and the meridional transport of this energy that is required to establish a global balance. Liquid clouds play an integral role in this exchange, enhancing reflection of solar radiation to space and thermal emission from the atmosphere to the surface as well as providing a mechanism for the direct transfer of energy to the atmosphere through the release of latent heat. As a result, visible, infrared, and microwave radiances from space-borne sensors have been used for a number of years to estimate the optical and microphysical properties of these clouds. Even after more than a decade of refinement, however, modern liquid cloud retrieval algorithms suffer from biases stemming from numerous assumptions of unobserved parameters required to constrain this inherently ill-posed problem.

As a prelude to our AMSR validation effort, we conducted a study to determine the extent to which the assumptions in different algorithms lead to biases in cloud liquid water path (LWP) estimates. LWP retrievals from the Visible and Infrared Scanning Radiometer (VIRS) were compared to collocated estimates from the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI). Considerable care was taken to precisely match VIRS and TMI pixels to remove any potential biases due to spatial mismatches in the data. Two experiments were conducted. In the first, visible radiances from the  $0.6 \mu\text{m}$  channel on VIRS were used to identify clear-sky pixels. LWP estimates from the TMI instrument for all such cloud-free pixels in January and July 1998 are presented in Figure 1. There are a number of regions where the TMI predicts non-zero LWP even when VIRS indicates no clouds are present. In fact, monthly-mean TMI clear-sky biases exceed  $0.05 \text{ kg m}^{-2}$  in some areas. Conversely, day-to-day variations in TMI clear-sky biases are generally less than  $0.02 \text{ kg m}^{-2}$ , suggesting that, while the biases may be large, random errors in the TMI LWP estimates are generally much smaller.

In the second experiment, LWP estimates from distinct TMI and VIRS-based retrievals are compared directly for all overcast warm cloud-only pixels in January and July, 1998. Referring to the results in Figure 2, significant differences are evident, generally coinciding with large-scale weather patterns. On average the TMI LWP estimates are  $\sim 30\%$  larger than those from VIRS on the monthly mean.

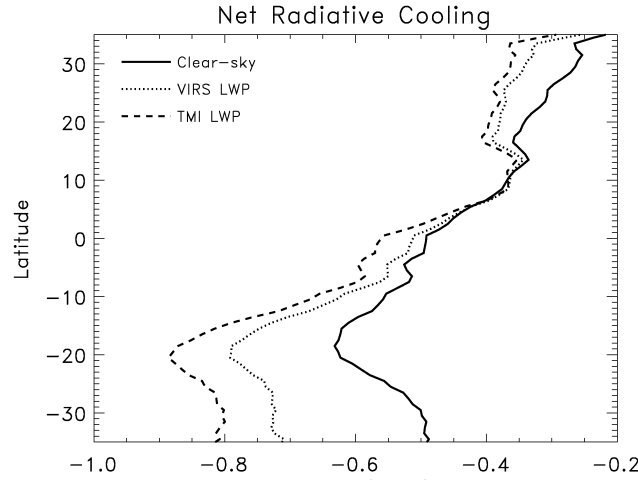


**Figure 1: Monthly-mean TMI LWP estimates (left panels) for cloud-free pixels determined from VIRS. The upper panels correspond to July 1998 while the lower panels are for January 1998. The panels on the right display the standard deviation in the TMI LWP estimates over the month. Note: only daytime pixels are displayed as the detection of cloud-free pixels is made based on visible radiances.**



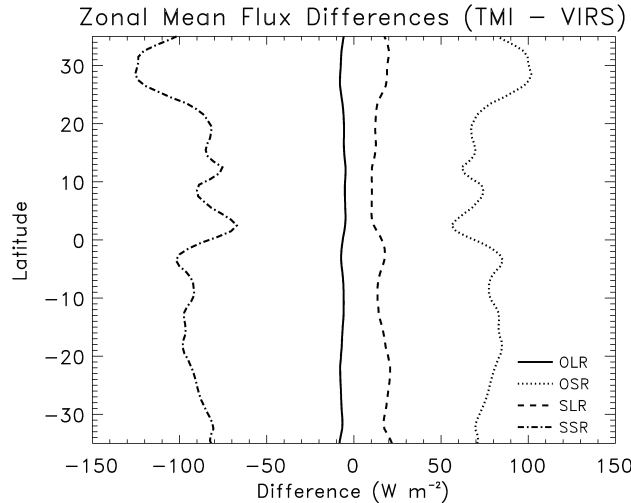
**Figure 2: TMI (left) and VIRS (right) LWP estimates for the months of July (top) and January (bottom) 1998.**

As stated above, liquid clouds play an important role in determining the exchange of radiation between the Earth, atmosphere, and space. Figure 3 illustrates how differences between the VIRS and TMI LWP estimates in Figure 2 translate into uncertainties in radiative fluxes at the top of the atmosphere and surface. Enhanced reflection of solar radiation by the larger TMI LWP is evident as outgoing shortwave radiation is increased by almost  $70 \text{ W m}^{-2}$ . Total shortwave radiation reaching the surface is reduced by  $80 \text{ W m}^{-2}$  due to the additional effect of enhanced absorption by the TMI-retrieved clouds. Finally, the added liquid water in the atmosphere leads to enhanced emission of approximately  $20 \text{ W m}^{-2}$  relative to the VIRS retrievals. These differences correspond to a  $\sim 25\%$  increase in the cloud component of net radiative cooling in the atmosphere as illustrated in Figure 4. Since the distribution of diabatic heating in the atmosphere is critical for the development and maintenance of weather systems around the planet, these results have serious implications for climate study and data assimilation applications.



**Figure 3: Differences in zonal mean radiative fluxes using TMI and VIRS estimates of liquid water path for all daytime overcast warm cloud pixels in the month of July, 1998. Outgoing longwave radiation (OLR), outgoing shortwave radiation (OSR), and downwelling longwave and shortwave radiation at the surface (SLR and SSR).**

These results, obtained as part of some background work for the AMSR validation effort, demonstrate the importance of improving assumptions in passive microwave LWP retrievals. The AMSR instrument differs from the TMI only by the presence of an additional low frequency channel and its LWP estimates are, therefore, likely to be susceptible to similar biases as those presented above. A component of our research in the upcoming year will be devoted to using a combination of radar and radiometer data from field campaigns in an effort to resolve these biases.



**Figure 4: Net atmospheric radiative cooling under clear-sky conditions and in the presence of TMI and VIRS-derived liquid clouds for daytime pixels in the month of July 1998.**

## 2. The Wakasa Bay Experiment (R. Austin)

The Wakasa Bay field campaign has provided a broad array of measurement data for use in the validation of AMSR-E products and the development of new combined retrieval algorithms. The experiment was conducted over the Sea of Japan, the Japanese Islands, and the Western Pacific Ocean from 6 January to 14 February 2003. This field experiment, featuring flights by the NASA P-3 Orion aircraft and Japanese contributions of in situ aircraft measurements and ground-based radar coverage, was central to the goals of this research project. Our participation in the experiment is chiefly tied to data collected by the UMass/JPL Airborne Cloud Radar (ACR), which operates at 94 GHz. This is the same frequency used by the CloudSat Profiling Radar (CPR): in addition to supporting AMSR-E validation goals, the ACR measurement activities also have relevance to the CloudSat mission. CloudSat provided significant support for the participation of the ACR; coordinating validation activities between CloudSat and AMSR-E is one of the goals of this project, for reasons of cost savings and exploring the synergies made possible by combining data from CloudSat and AMSR-E. CloudSat will fly in formation behind the Aqua platform after launch in 2004.

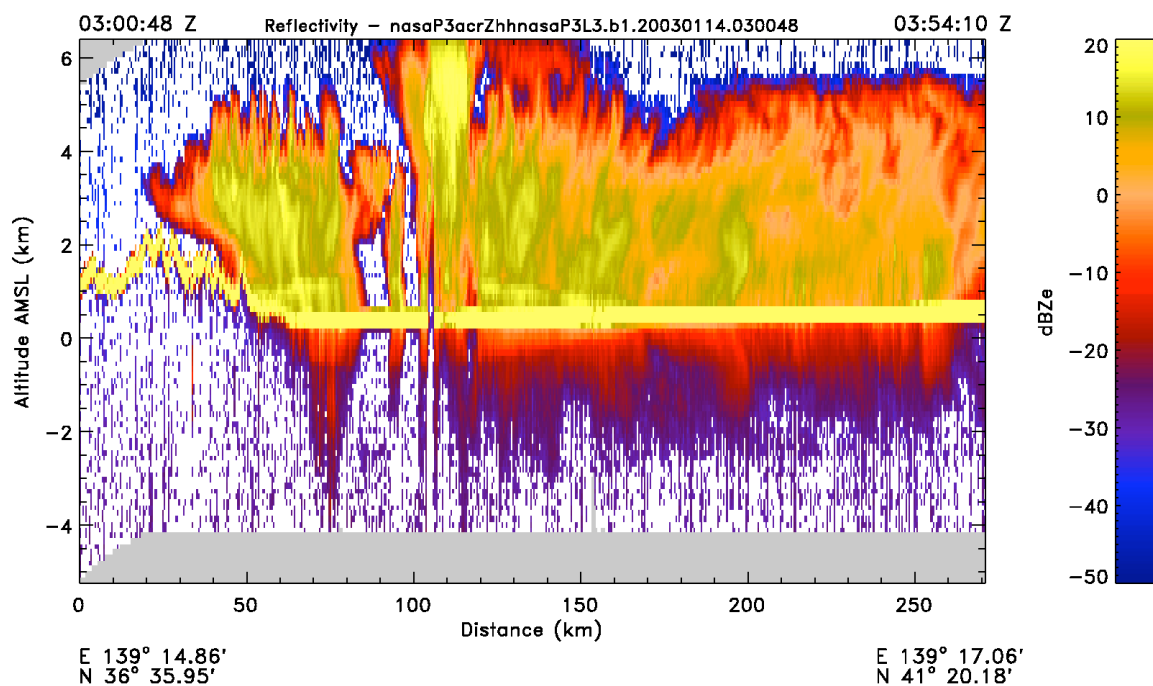
The Wakasa Bay field campaign was highly successful. A variety of rain, snow, and cloud systems were observed by the full complement of instruments on the P-3 over both ocean and land, and a number of flights featured either simultaneous in situ measurements by the Japanese Gulfstream II jet or low-altitude flight legs flown by the P-3 itself. A preliminary summary of the twelve science flights is shown in Table 1.

Flight	Date	ACR	PR-2	PSR	AMMR	MIR	Gulfstream Low flight	Location	Satellite Overpass	Comments
1	14-Jan-03	✓	✓		✓	✓	✓	Sea of Japan	A	Rain then snow, BB visible
2	15-Jan-03	✓	✓	not 89	✓	✓		W Japan, GTS	-	Snow & some rain over land; brief water crossing
3	19-Jan-03	✓	✓	✓	✓	✓	✓	W Pacific	A	Warm rain cells, frontal cross, BB visible, occ. ACR total atten., light icing high
4	21-Jan-03	✓	✓	✓	✓	✓	✓	W Pacific	A*	Snow/rain, occasional BB
5	23-Jan-03	✓	✓	✓	✓	✓		W Pacific	T(x3)	Strong & widespread rain, supercooled water, BB visible, squall line
6	26-Jan-03	✓	✓	✓	✓	✓		W Japan, GTS	A	Weak cloud, mostly clear
7	27-Jan-03	✓	✓	✓	✓	✓	✓	Sea of Japan	-	Stratiform rain or cloud only; strong rain during return over land
8	28-Jan-03	✓	✓	✓		✓	✓	Sea of J, GTS	A,T	Oceanic snow cells, also rain, mixed precip?, 10° bank turn, snow over land
9	29-Jan-03	✓	✓	✓		✓	✓	Sea of J, GTS	-	Heavy snow over ocean (up to 5 km), also snow over land
10	30-Jan-03	✓	✓	✓		✓	✓	Sea of J, GTS	A,T	Strong snow cells, clear & cloud-only areas, 15°/20° turns, snow over land
11	01-Feb-03	✓	✓	✓	✓	✓		W Japan, GTS	A,T	Thin Sc, fresh snow on surface
12	03-Feb-03	✓	✓	✓	✓	✓	✓	W Pacific	A,T	Scatt rain cells, fly through melting layer, icing above, 10° bank turn

Table 1 Preliminary summary of 12 Wakasa Bay science flights. (GTS = ground truth site at Fukui, BB = radar bright band, satellites A and T are Aqua and TRMM)

Sample preliminary time-height profiles of ACR-measured effective radar reflectivity factor are shown in Figures 5, 6, and 7. The UMass data team are in the process of processing the ACR data and applying navigation data corrections. Once that is completed, we will begin analysis of this data set on several fronts.

The variety of cloud and precipitation types observed during the Wakasa Bay campaign will allow for the validation and development of a number of algorithms. Simple retrievals of cloud liquid and ice water content and particle size have been recently developed (Austin and Stephens 2001, Benedetti et al. 2003); these will be applied in precipitation-free regions or regions where precipitation is deemed to be extremely light, in order to observe the loss of accuracy as precipitation increases. Retrievals of cloud LWP will be compared with AMSR algorithms. A precipitation retrieval algorithm for attenuating radars (L'Ecuyer and Stephens 2002) will be applied to regions containing very light to moderate to heavy precipitation, for comparison to AMSR precipitation estimates and to observe the performance of the retrieval algorithm across different precipitation regimes. Wakasa Bay data will also provide numerous test data sets for retrievals of snow and drizzle; development of these retrievals is in the preliminary stages and will be emphasized in the coming year.



**Figure 5** ACR Reflectivity from the approach and first flight line on 14 January 2003 (Flight 1). This data segment begins over Honshu and continues over the Sea of Japan. A bright band is visible at about 1 km altitude near the coast, descending to the water surface as the line progresses north.



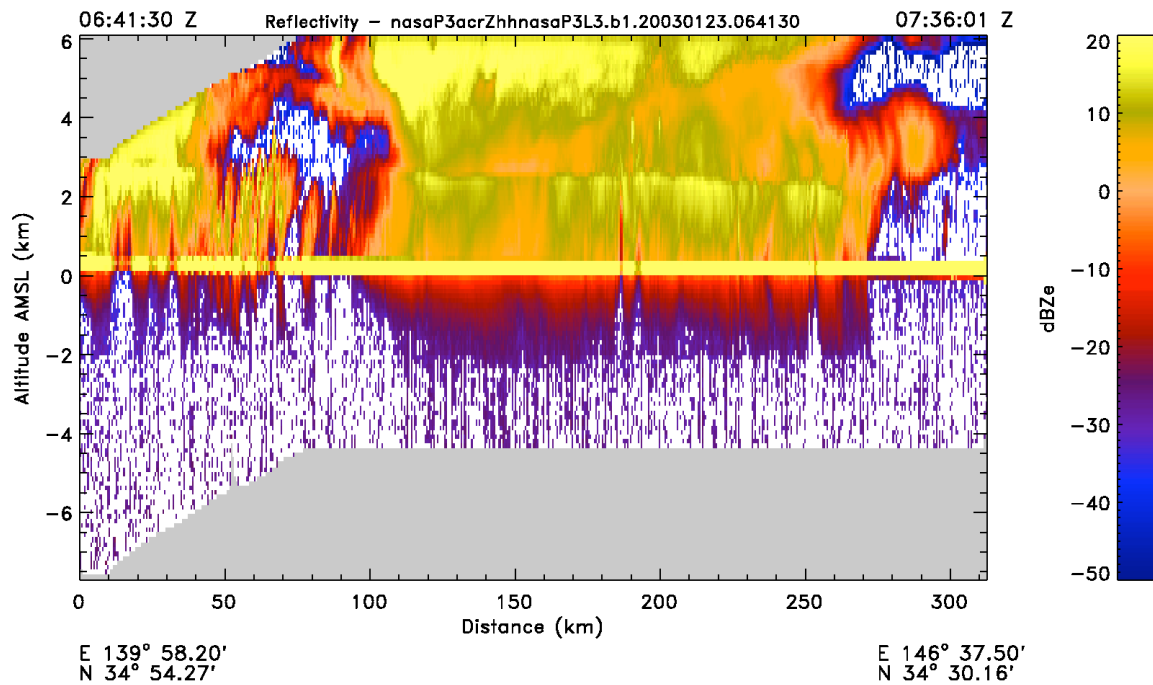


Figure 6 ACR reflectivity from the first flight line on 23 January 2003 (Flight 5). This line extended over 300 km over the Pacific Ocean. The P-3 was flying through the top of the cloud layer; a bright band is visible at about 2.2 km above the surface.

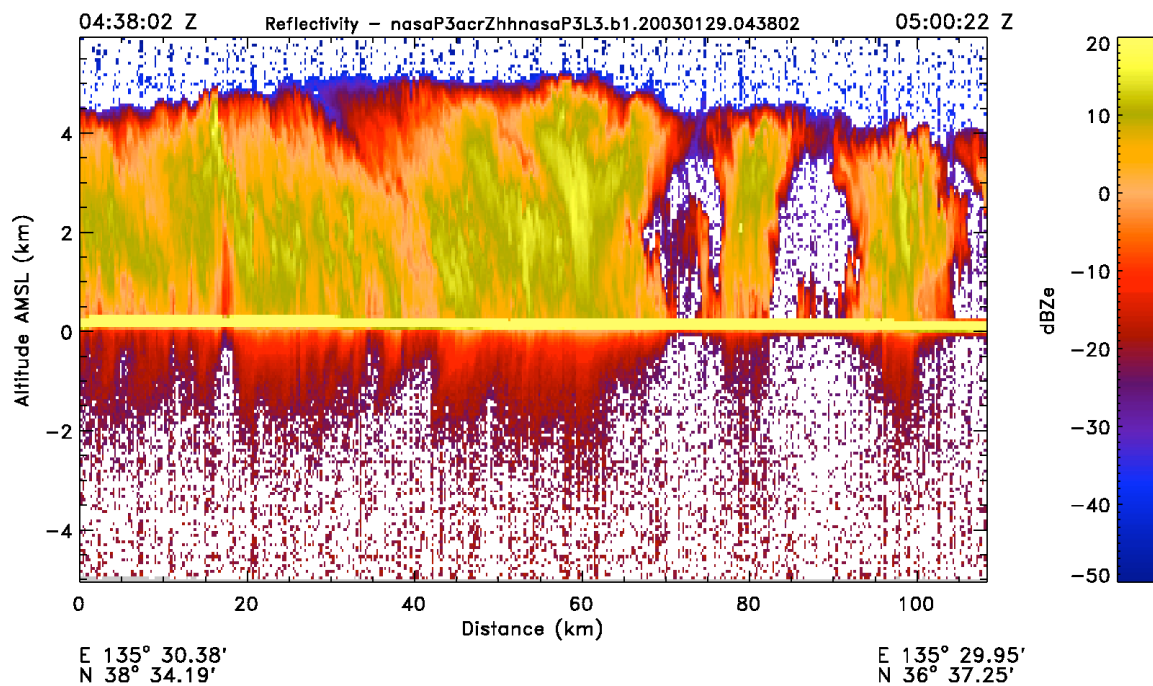


Figure 7 ACR reflectivity from a flight line on 29 January 2003 (Flight 9). Heavy snow with extensive vertical development was observed along this line over the Sea of Japan. ACR data was collected at 60-meter vertical resolution during this flight line.

### **3. Plans for the coming year**

We have a number of activities planned for the coming year:

1. Submit ACR data to the DAAC
2. Perform cloud liquid and ice water content retrievals (where the retrieval algorithms are valid), either from radar alone or in combination with Aqua-MODIS overpasses. Compare results to AMSR retrievals.
3. Perform retrievals of light (liquid) precipitation, either from radar alone or in combination with PSR data or Aqua overpasses. Compare results to AMSR retrievals.
4. Study the transition from ice to mixed phase to liquid and from liquid cloud to drizzle to light precipitation, and the consequent ranges of validity of the various cloud and precipitation retrievals
5. Perform preliminary retrievals on snow

### **4. Data Management**

Data sets from ACR measurements during Wakasa Bay flights are currently being processed and navigation-corrected at the University of Massachusetts. We plan to submit the following data products to the DAAC around the end of March 2003:

- Co-polarized ACR effective radar reflectivity factor (94 GHz)
- Cross-polarized ACR effective radar reflectivity factor
- ACR Doppler velocity

Other data products based on ACR data, such as cloud liquid and ice water paths and precipitation estimates, will be available to the AMSR-E validation team later in 2003.